EGR Catalyst for Cooler Fouling Reduction

May 2007

CLEERS Workshop
Dearborn, MI

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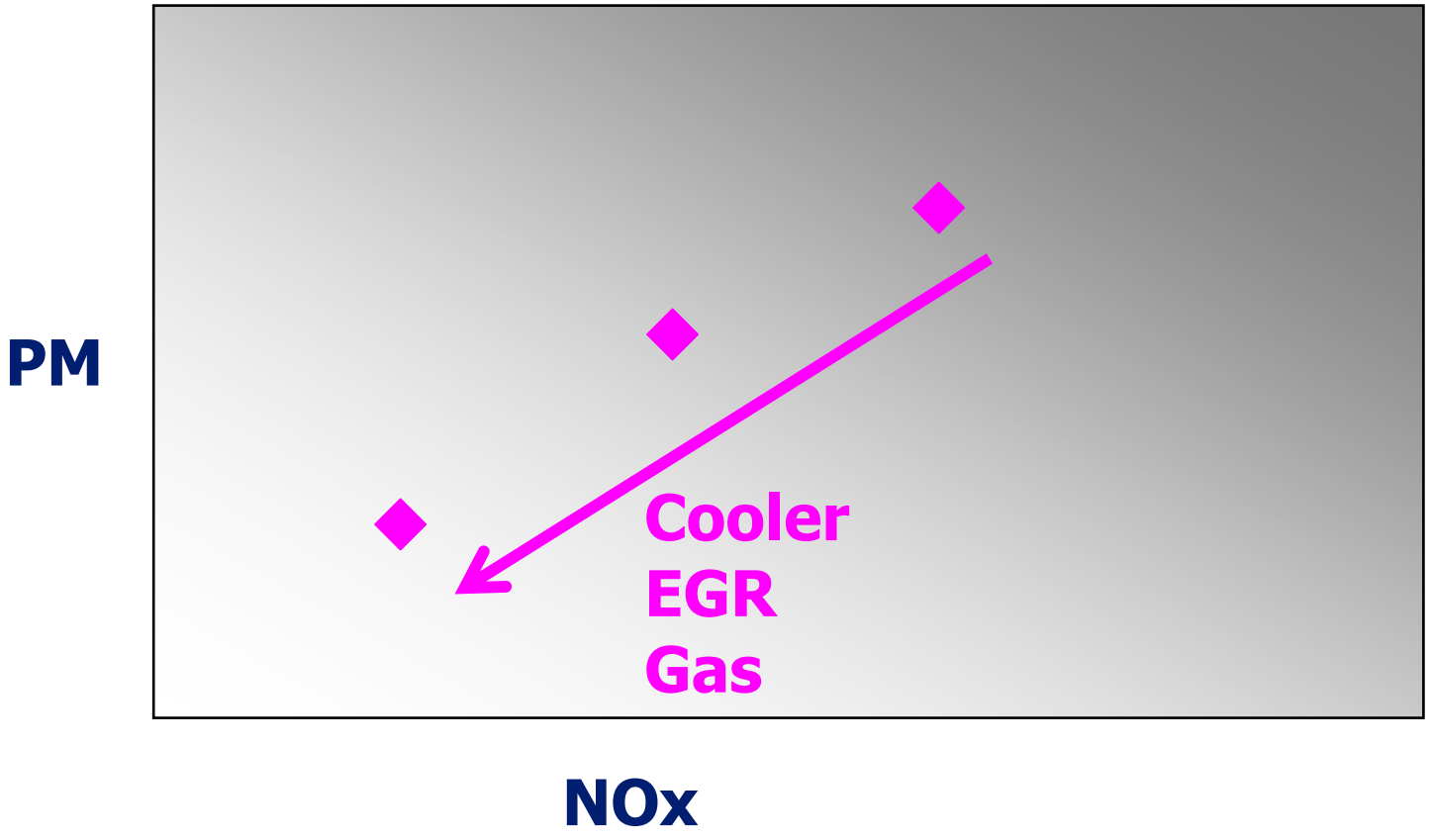
Acknowledgements

- Jimi Tjong and his dynamometer group at the Ford Canada Essex Engine Plant ran the cooler fouling engine tests
- Oak Ridge National Lab performed some of the analyses shown – Scott Sluder, John Storey, Sam Lewis
- Johnson Matthey Environmental Catalysts and Technologies provided the catalysts used in these experiments

Increased EGR Cooling required

- Future emission standards: lower NOx, PM
- Reduced charge temperature helps (see next slide)
  - EGR is cooled
  - Bigger coolers
  - Lower temperatures

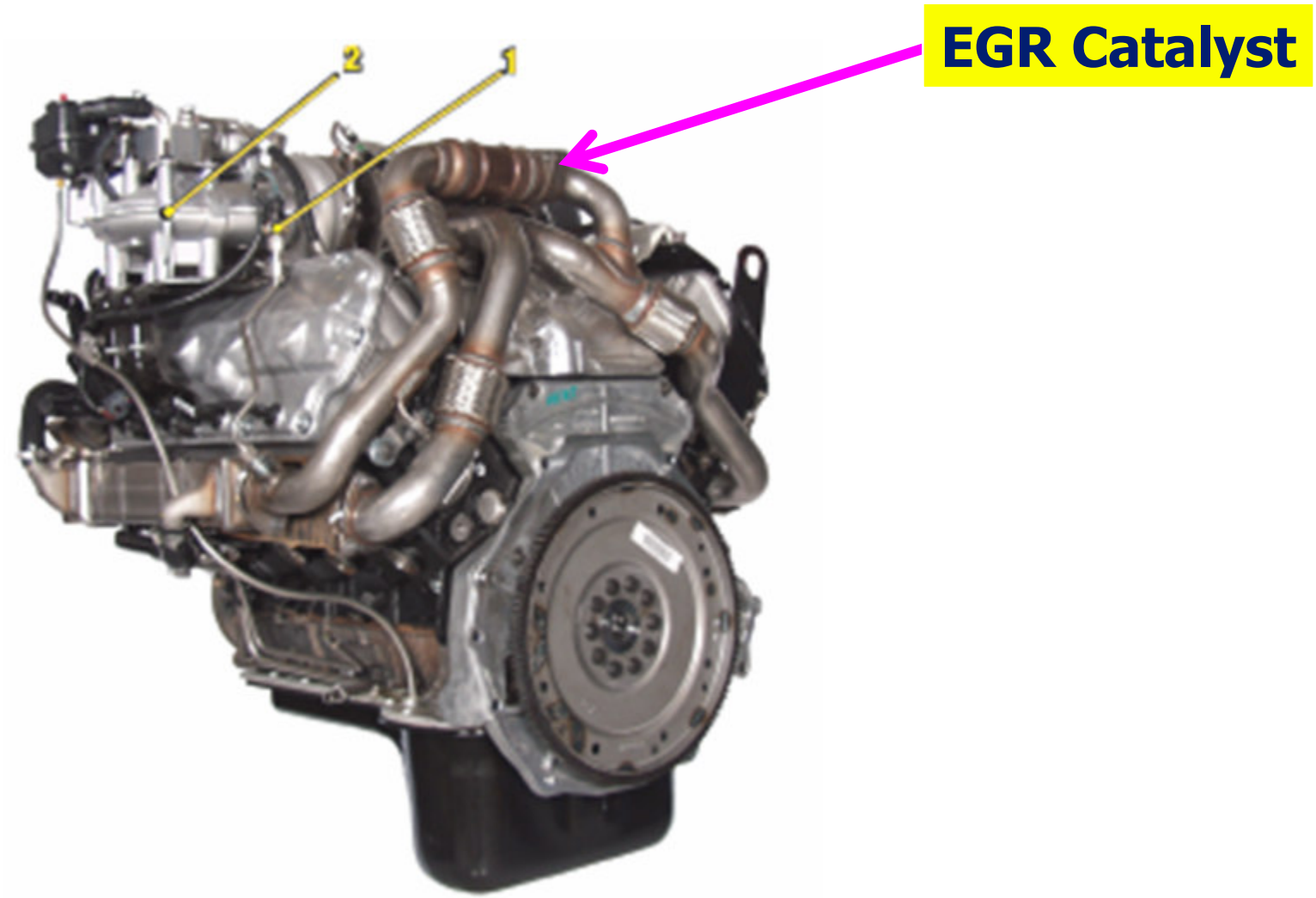
Improved EGR Cooling Reduces NOx and PM



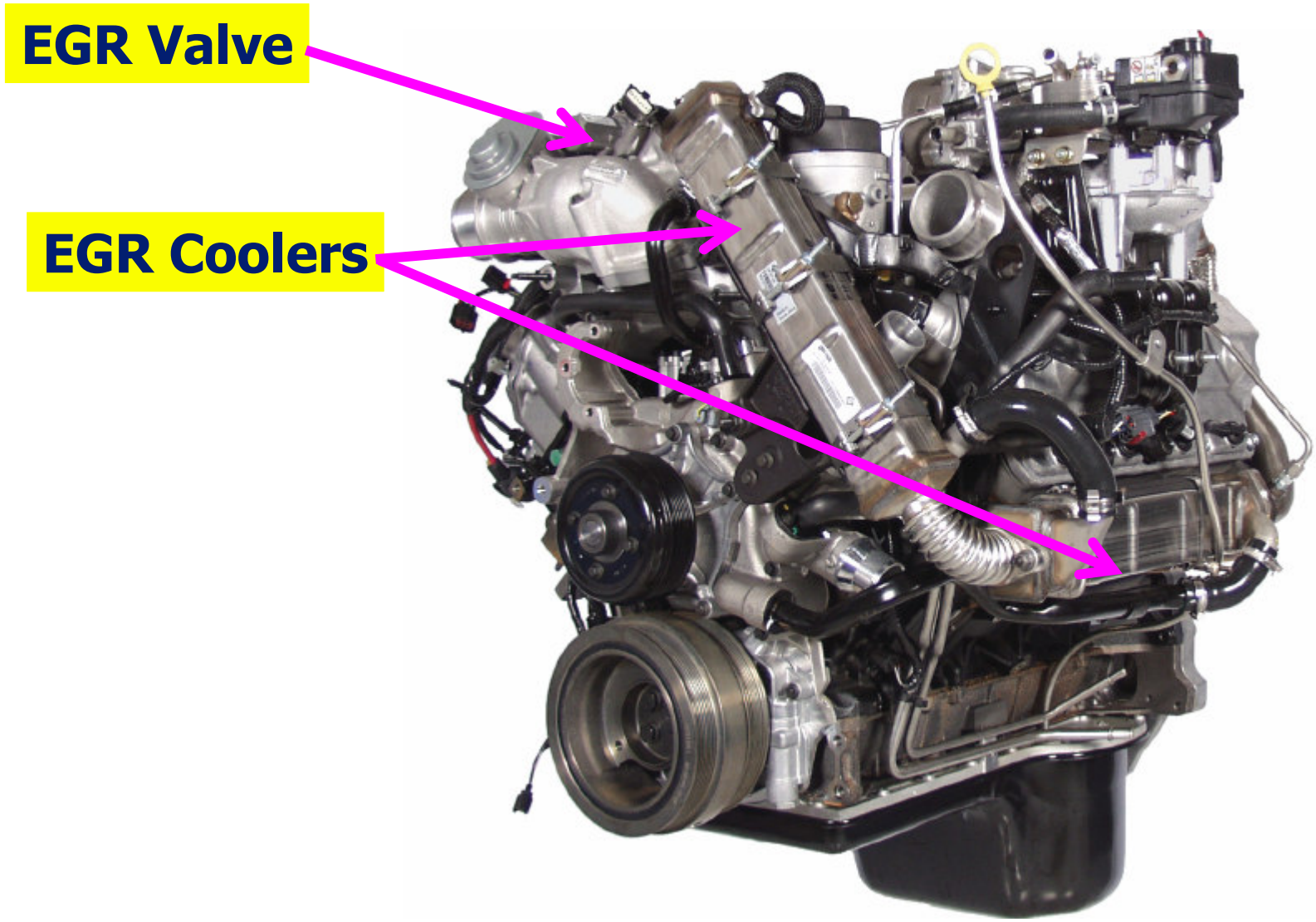
Deposits

- Cool surfaces exposed to gas collect deposits:
  - Soot - thermophoresis
  - Hydrocarbons - condensation
  - Partially oxidized and pyrolyzed HC
  - Acids – sulfuric, nitric, formic, acetic
- Deposit concerns are worse when
  - Wall temperatures are low
  - "Heavy Wet PM" – more likely at low-NOx calibrations
- Likely to get worse with future calibrations for very low NOx levels!

Test Engine – Rear View



Test Engine – Left Front View



Engine Dynamometer Cooler Fouling Test Cycle

Mode	*RPM*	*Load ft-lb*	T_{inlet} *°C*	*Space Velocity khr⁻¹*
Idle	700	50	150	127
A25	2100	166	250	503
HSV	2300	300	350	1147

- **Two hours at each point in order**
- **Repeat until effectiveness stabilizes**

Response Variables

- Effectiveness

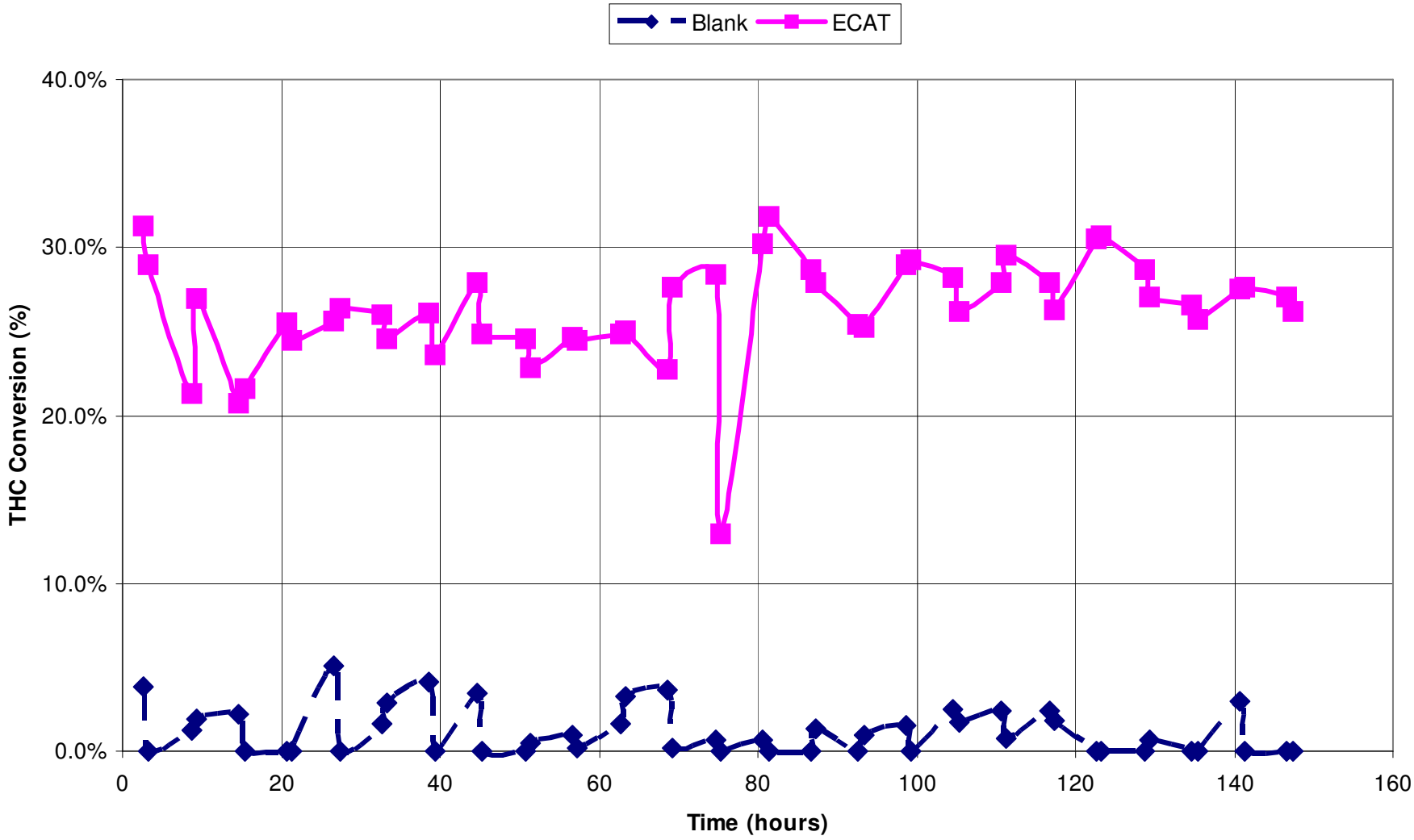
$$\varepsilon = \frac{q_{actual}}{q_{max\text{-}theoretical}} = \frac{m_{exh}\, C_{p,exh}\, (T_{exh,i} - T_{exh,o})}{m_{exh}\, C_{p,exh}\, (T_{exh,i} - T_{coolant,o})} = \frac{(T_{gas\ in} - T_{gas\ out})}{(T_{gas\ in} - T_{coolant\ in})}$$

- ECAT HC conversion efficiency

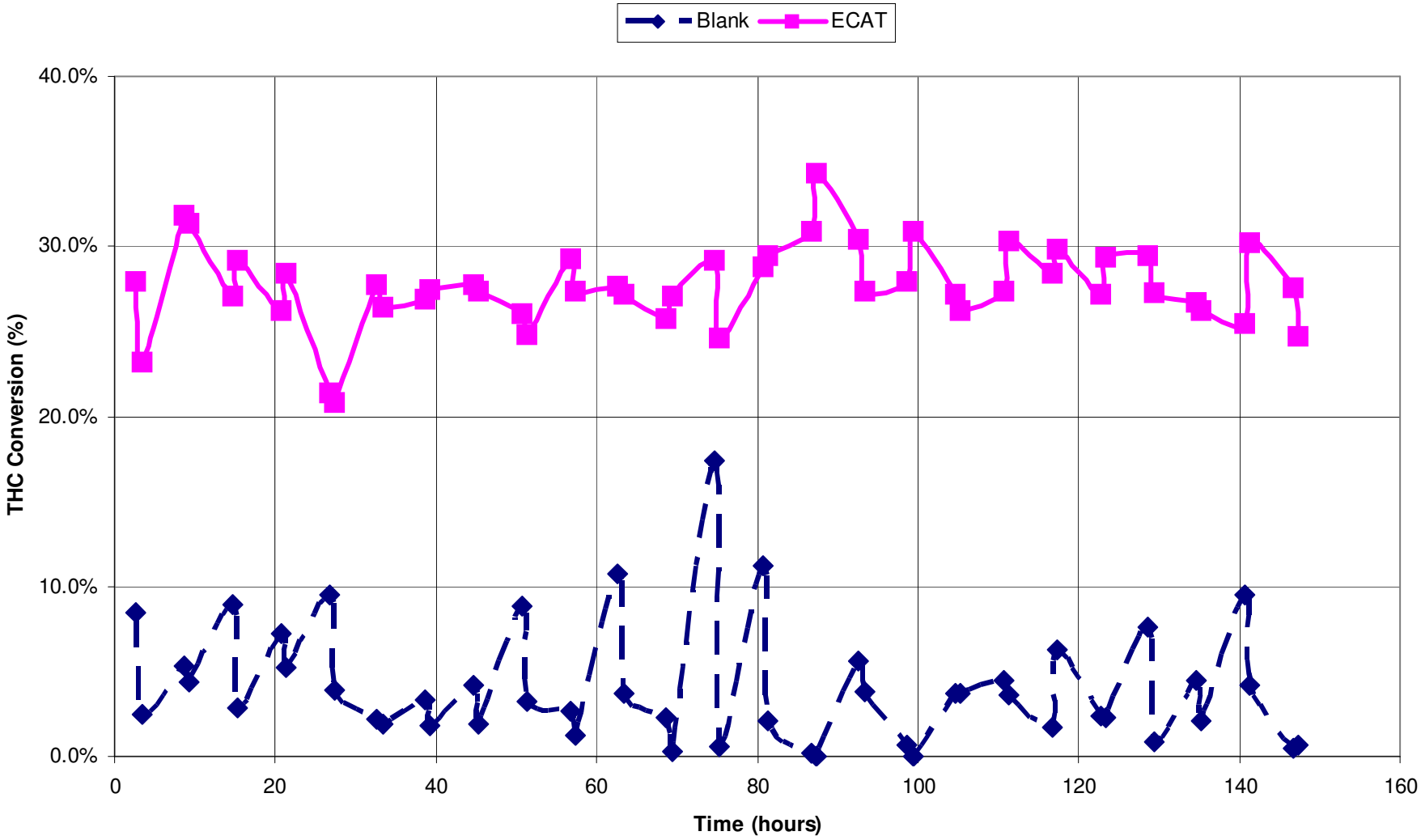
Fouling Test – ECAT Effect

- Cooler fouling test run with ECAT, and with blank ECAT
- ECAT
  - 200 cpsi metallic substrate
  - 60 mm diameter by 90 mm long, 0.24 L volume
  - Oxidation catalyst formulation
  - Compared to coated monolith without PGM
  - Samples prepared for Ford by Johnson Matthey
- Test fuel
  - Canadian market 2005-2006 fuel
  - ~400 ppm sulfur
  - 25-30% aromatics

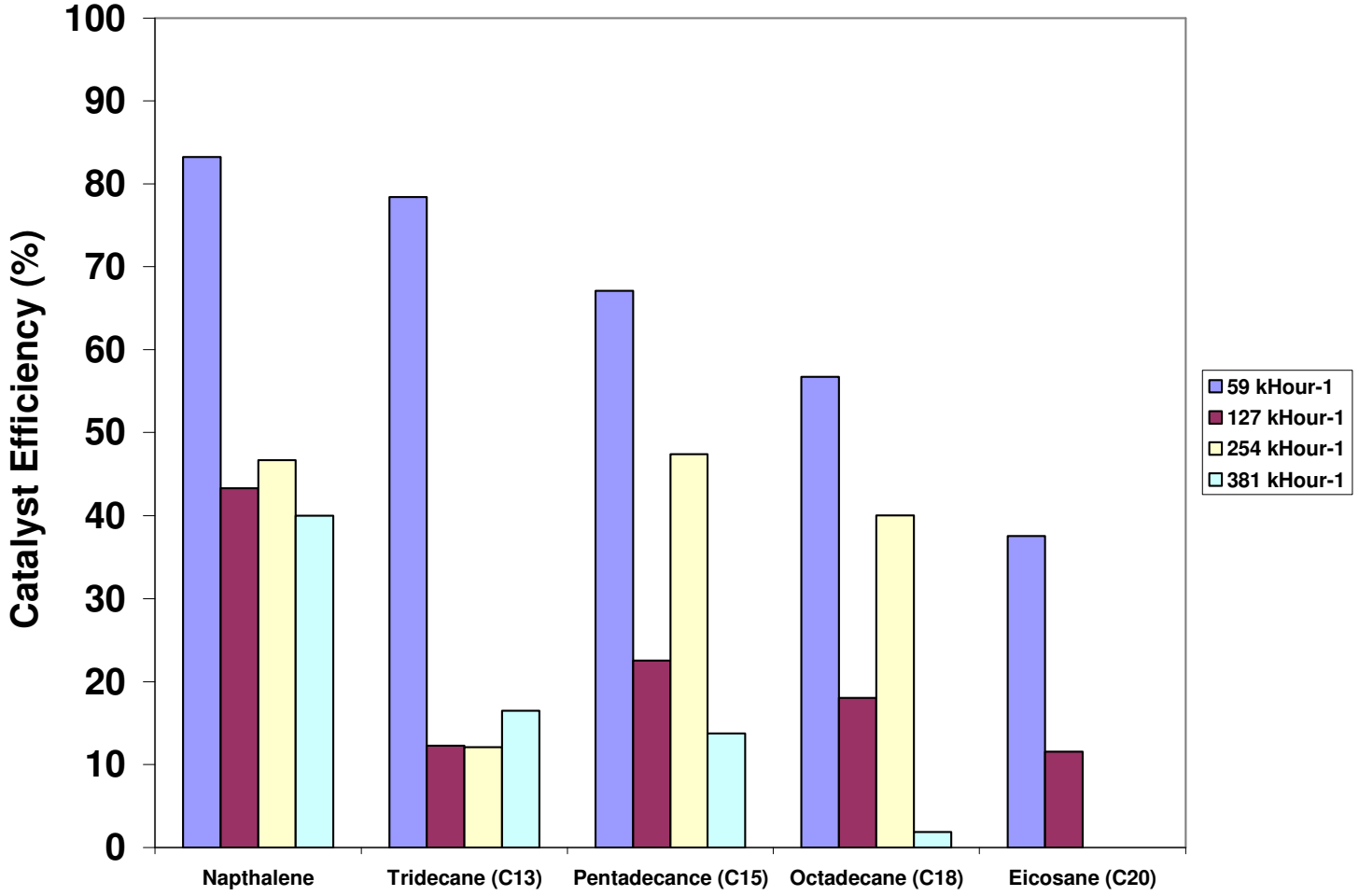
ECAT HC Conversion – A25



ECAT HC Conversion – HSV

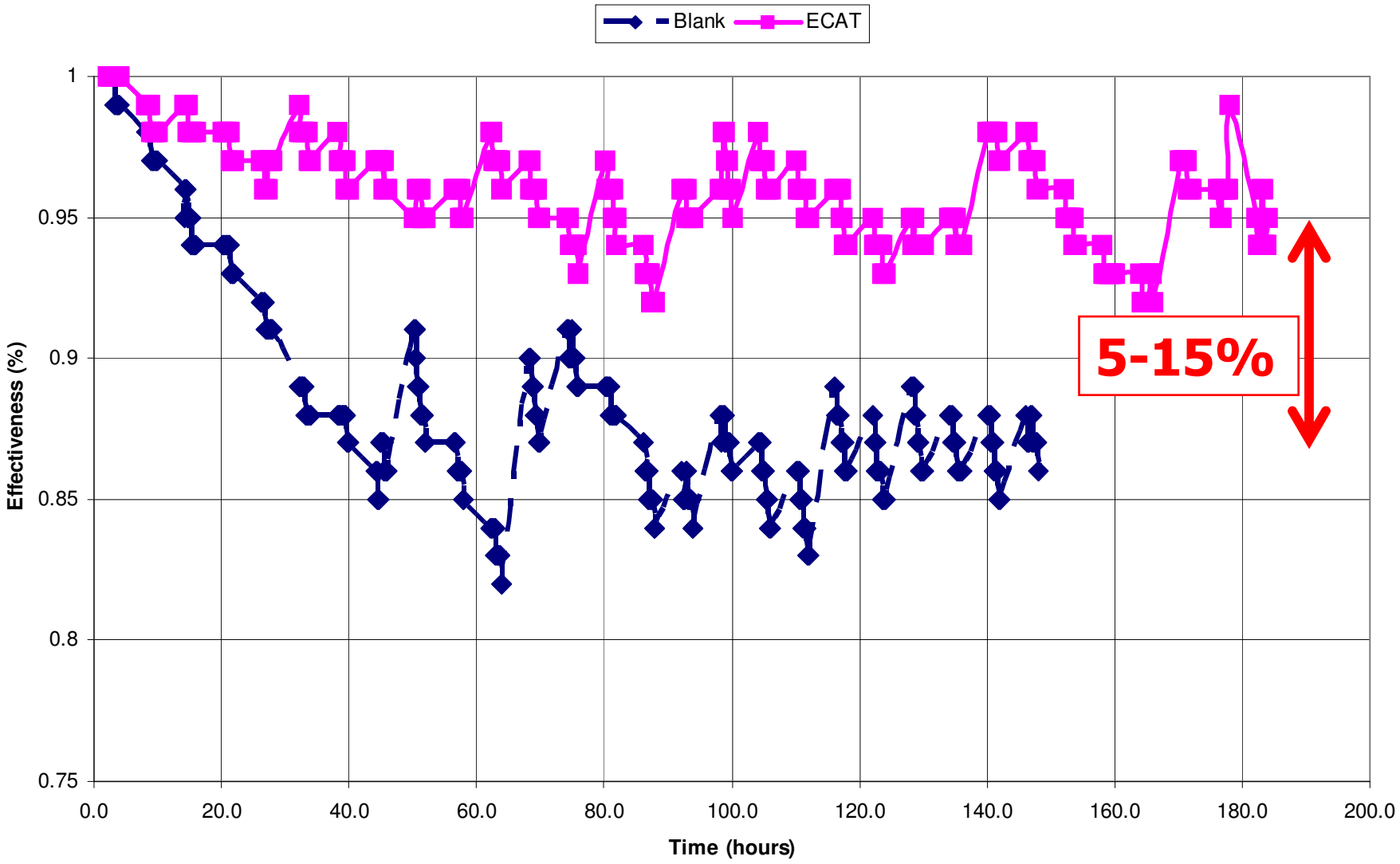


ECAT Conversion for Different Species and Space Velocity

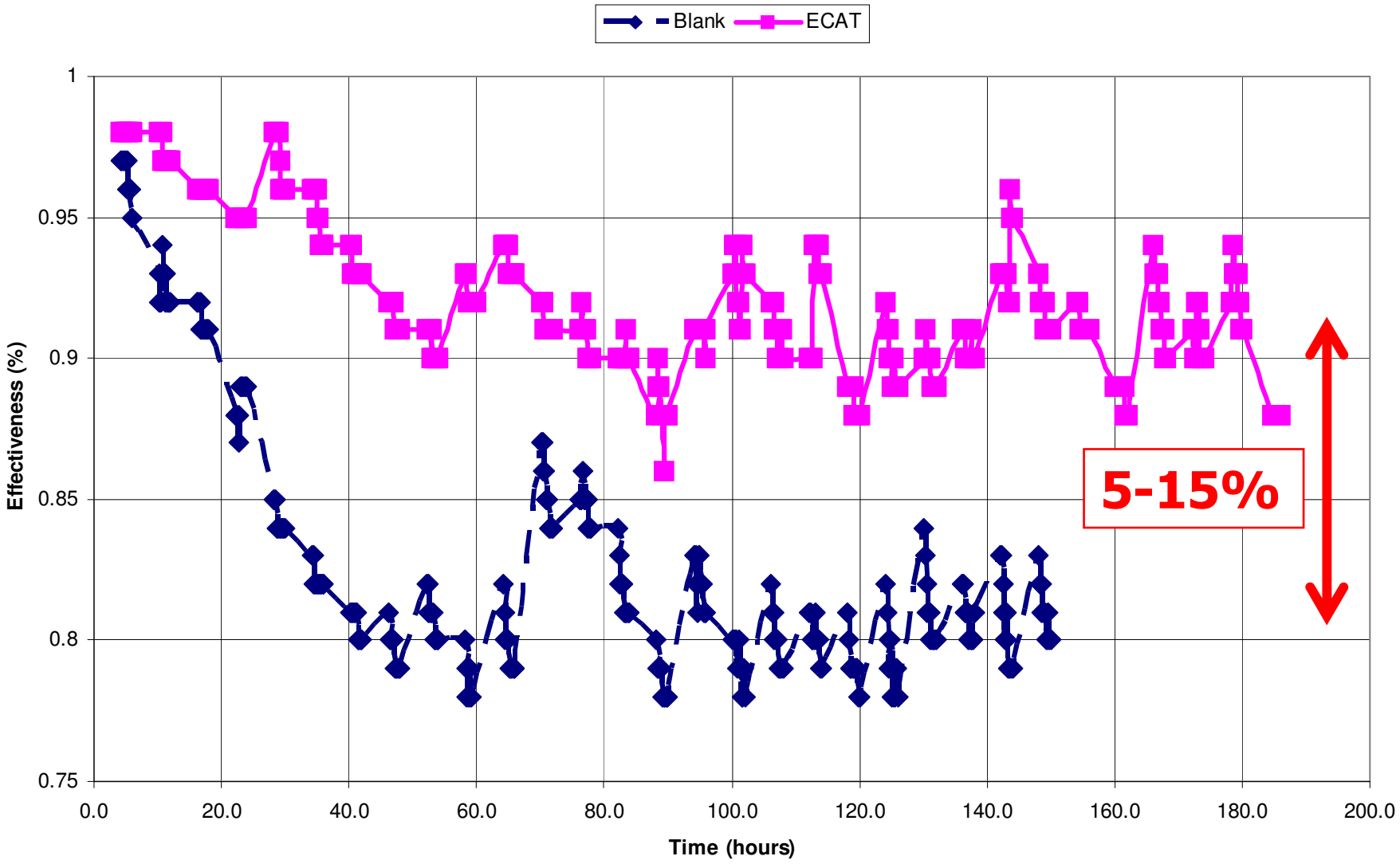


- Reference catalyst and engine
- Testing at ORNL

ECAT Effect on Effectiveness – A25



ECAT Effect on Effectiveness - HSV

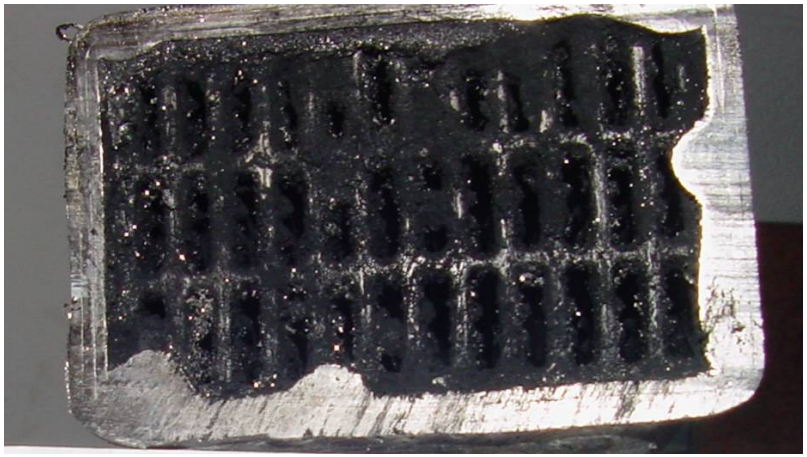


Cooler Deposit Analyses

- Following a fouling test with ECAT
- Deposits were analyzed at ORNL

Deposits

Cooler 1 Inlet

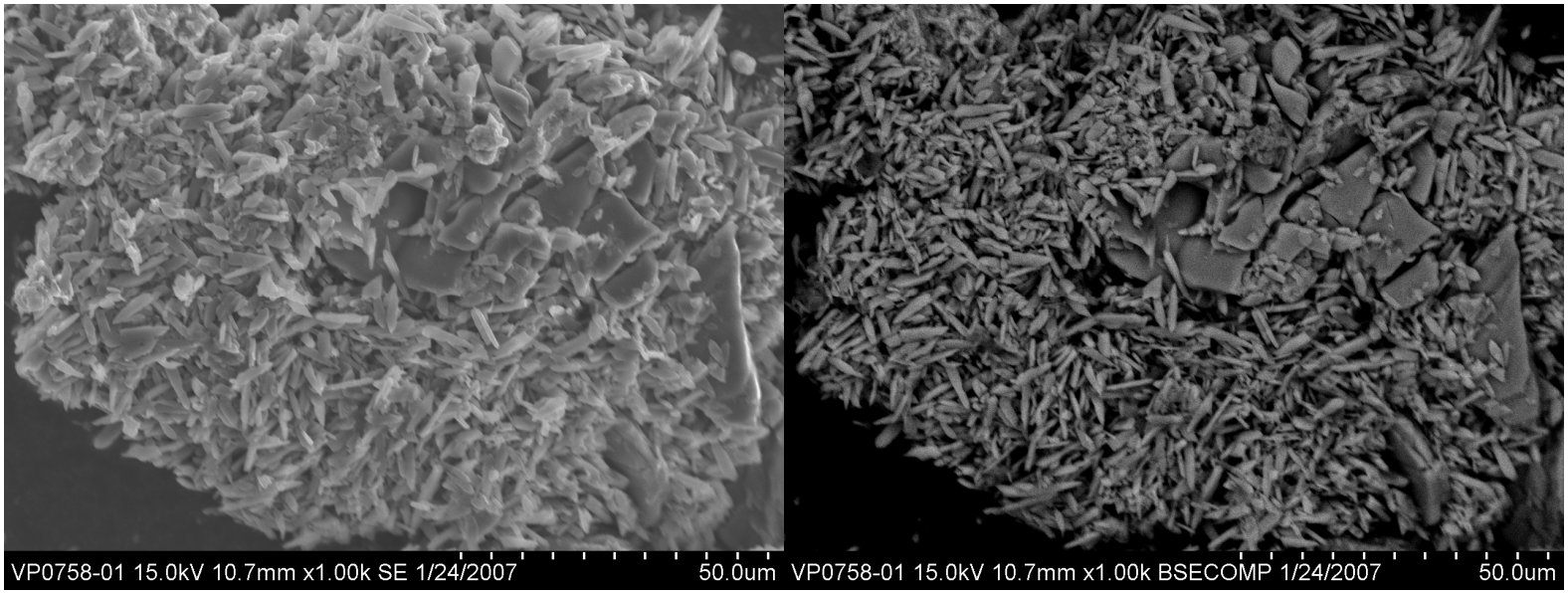


Cooler 2 Inlet

Electron Microscopy of "Ash" Particles Showed Significant Sulfate Fraction

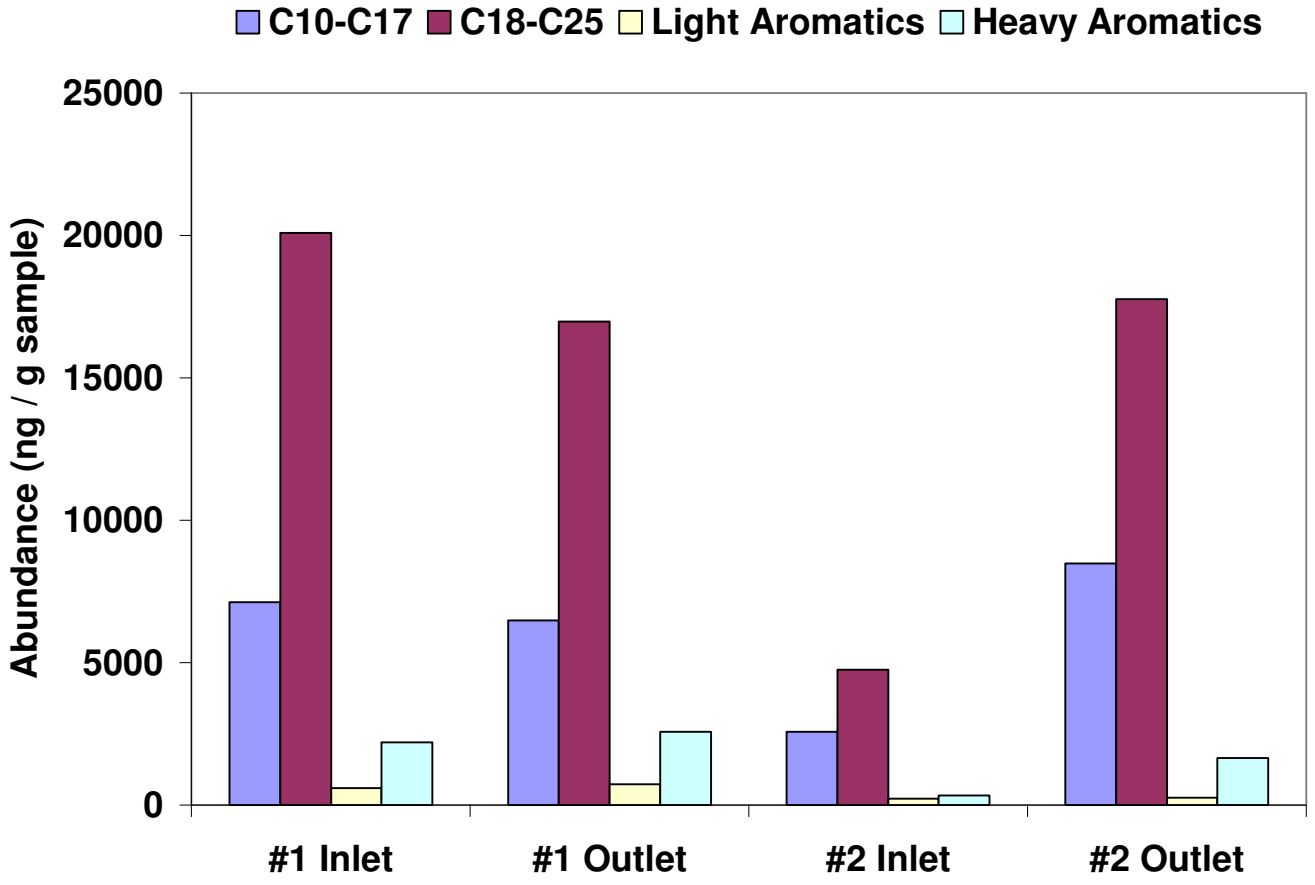
Secondary Electron Image

Back-Scattered Electron image

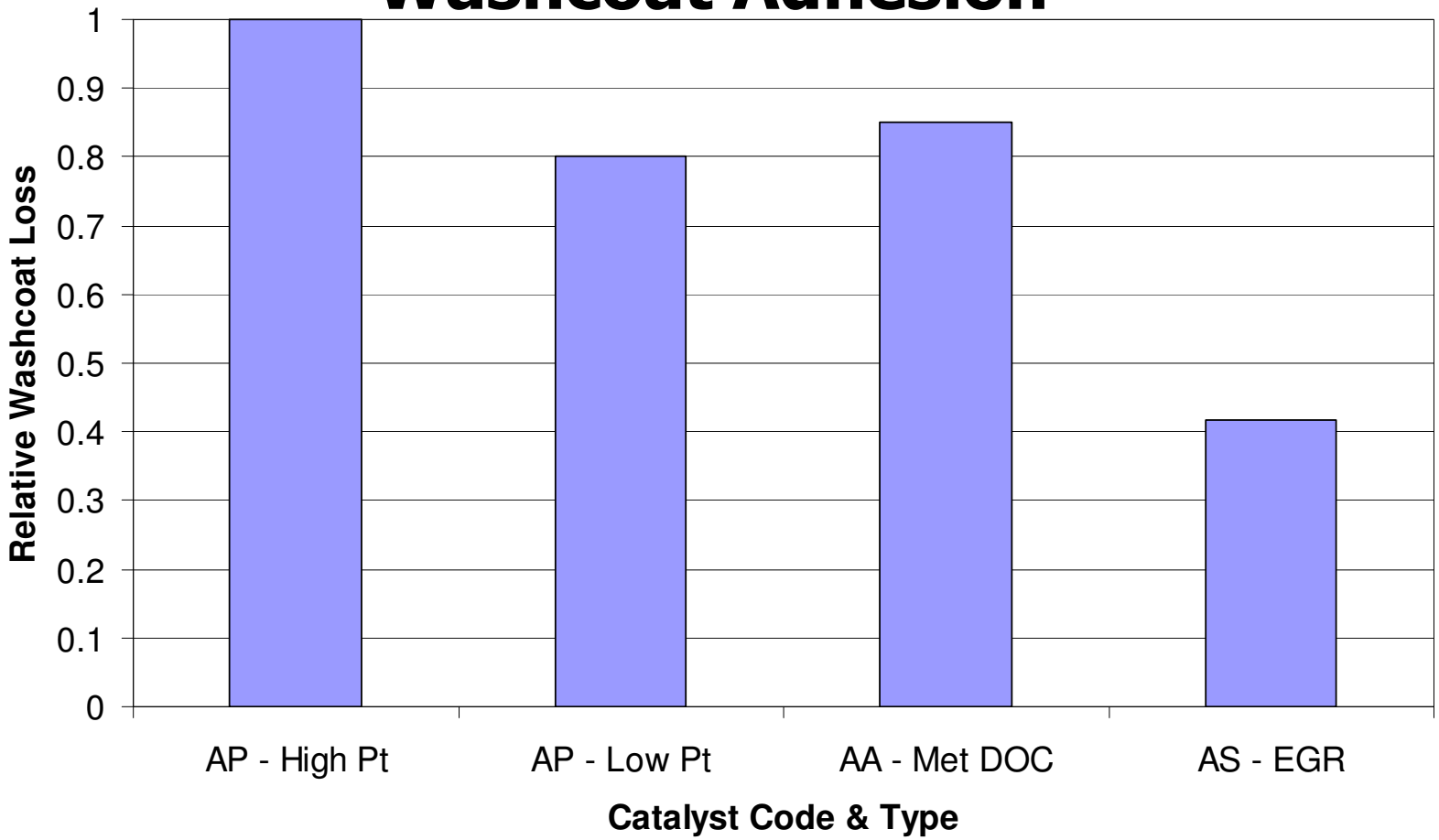


- **A significant percentage of the soot was composed of a sulfate phase shown here. The sulfate appeared like grains of rice approximately 5 to 10 microns long and 2 microns wide.**
- **Consistent with oxidation of fuel sulfur by ECAT; also consistent with fuel sulfur content.**

Chemical Extraction and Analysis Showed that Deposit HCs were Dominated by the Heavy Fraction.



Washcoat Adhesion



- Washcoat loss puts powder into engine
- Development improved adhesion
  - "AS" versus earlier designs

Conclusions

- An ECAT has reduced the rate of EGR cooler fouling
- This can be accomplished with a remarkably high SV
- Washcoat adhesion improved

Thanks For Your Attention…..

- Questions?